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EVALUATION OF VARIOUS OPTIONS FOR THE COMPRESSION AND DISTRIBUTION OF COMPRESSED HELIUM GAS TO THE SATELLITE REFRIGERATION SYSTEM OF THE ENERGY DOUBLER

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FOR

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I N D E X

Section	Title	Page No.
1	INTRODUCTION	2
2	PRESSURE DROP IN NORMAL BALANCED SYSTEM	6
3	PRESSURE DROP IN UNBALANCED SYSTEM DUE TO ONE COMPRESSOR BREAKDOWN	8
4	SCREW COMPRESSORS, SIZE AND COMBINATIONS	
5	COST OF COMBINATIONS	
6	CONCLUSIONS	

EVALUATION OF VARIOUS OPTIONS FOR THE COMPRESSION AND DISTRIBUTION OF COMPRESSED HELIUM GAS TO THE SATELLITE REFRIGERATION SYSTEM OF THE ENERGY DOUBLER

1. Introduction:

The basic requirement is 24 times 50 gm/sec (1,200 g/sec) of helium gas to be distributed to 24 satellite refrigerator cold boxes. Spacing of the cold boxes is at 800 ft intervals. The tunnel will contain an 8 in. IPS, Schedule 5 pipe which will run in parallel with the doubler. This pipe will be used for various purposes, as follows:

a) Collect gas during cooldown of the magnets.

b) Collect gas during quenches of parts or all of the accelerator.

c) Collect gas from leads and safety leads.

Compressed gas will be returned to the CHL from each satellite station through a 3 in. IPS, Schedule 5 pipe which will be located outside the tunnel and parallel the ring.

Under normal operating conditions of the doubler, 46.1 g/sec of helium gas at 20 atm and ambient temperature will be fed to the satellite refrigerator cold box. Gas is returned from the cold boxes at a rate of 50 g/sec at 1.05 atm and ambient temperature. This gas is compressed and 3.9 g/sec is returned to the CHL at a pressure of 20 atm.

Various combinations of compressor arrangements are possible. The basic arrangement is one compressor located at each satellite cold box. In that case, the 3 in. and 8 in. lines are not used for gas distribution between satellite cold boxes. A total of 24 compressors is required with power at each station. If one compressor drops out, gas may be supplied to that station from all other stations through the 3 in. line. The 8 in. line may be used to distribute low pressure gas to a number of adjacent compressors.

The purpose of this report is to examine other combinations of compressors, different size and number of compressors based on availability, and the final cost of any proposed alternatives to the basic system.

The following combination of number of compressors and number of stations were studied:

	# Stations	Compressors Per Station	Total Compressors
Case I	24	1	24
Case II	12	2	24
	12	1	12
Case III	8	3	24
	8	2	16
	8	1	8
Case IV	6	4	24
	6	3	18
	6	2	12
	6	1	6
Case V	4	6	24
	4	5	20
	4	4	16
	4	3	12
	4	2	8
	4	1	4
Case VI	3	8	24
	3	7	21
	3	6	18
	3	5	15
	3	4	12
	3	3	9
	3	2	6
	3	1	3

To compare the various cases, the pressure drop was calculated for the flow in the 3 in. and 8 in. pipelines. Calculations were made for 800 ft length sections of pipe based upon the flow through each of the sections for every case. Note that for Case I there is essentially no flow in the headers because each refrigerator cold box is supplied by its own compressor.

Figures I through VI indicate typical flow patterns for the various cases investigated. For simplification, flow values have been indicated in units where each unit represents 396.5 lb/hr (50.0 g/sec). The flow directional arrows represent discharge flow. For suction flow the unit values remain the same, but the directional arrows are reversed.

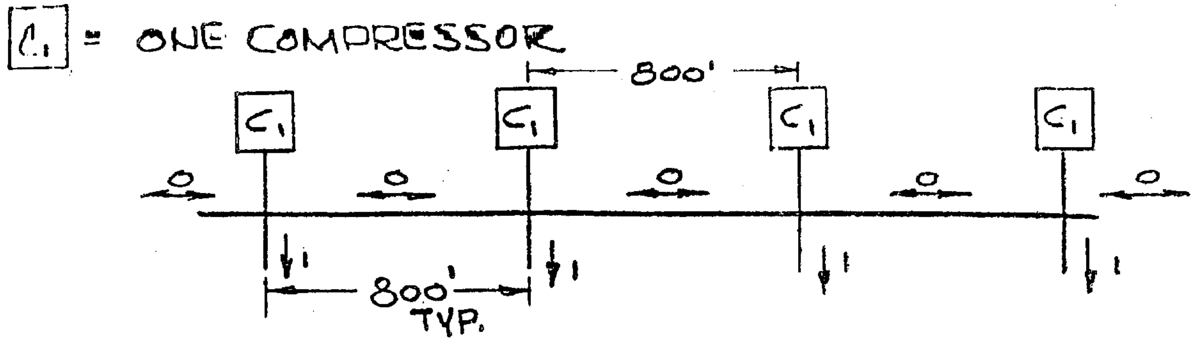

Fig. I: Case I - 24 Stations

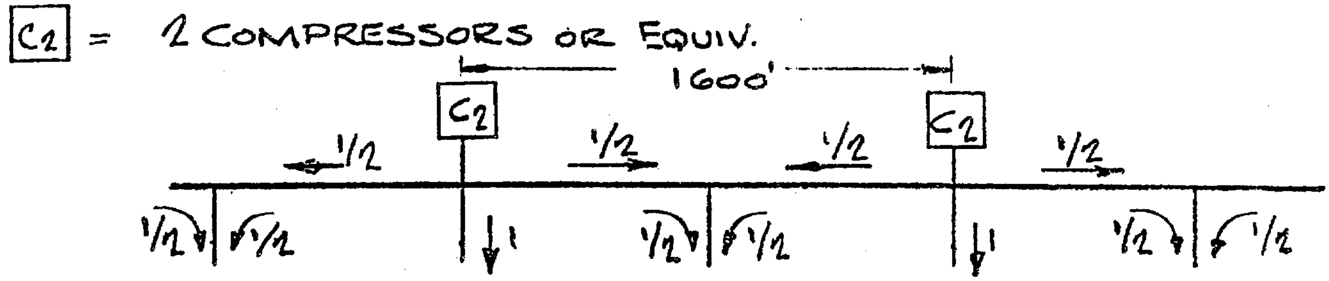

Fig. II: Case II - 12 Stations

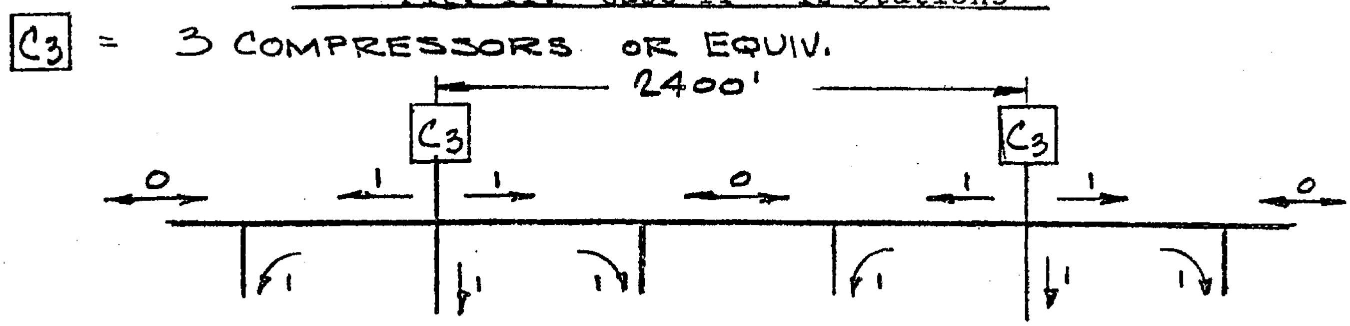

Fig. III: Case III - 8 Stations

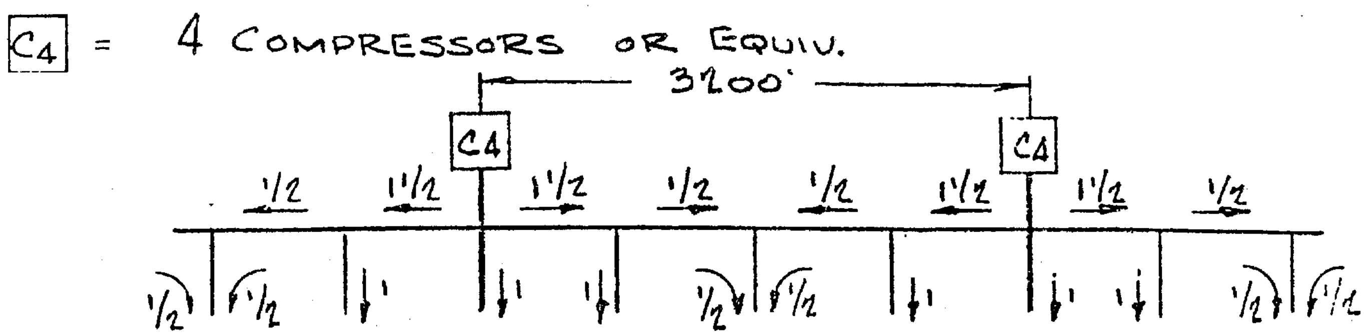

Fig. IV: Case IV - 6 Stations

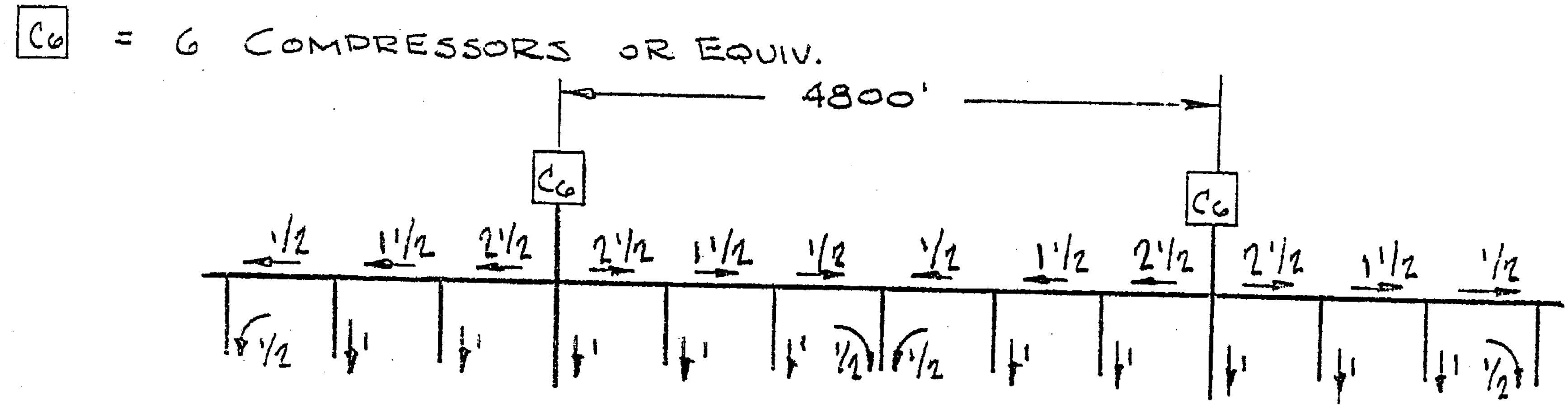

Fig. V: Case V - 4 Stations

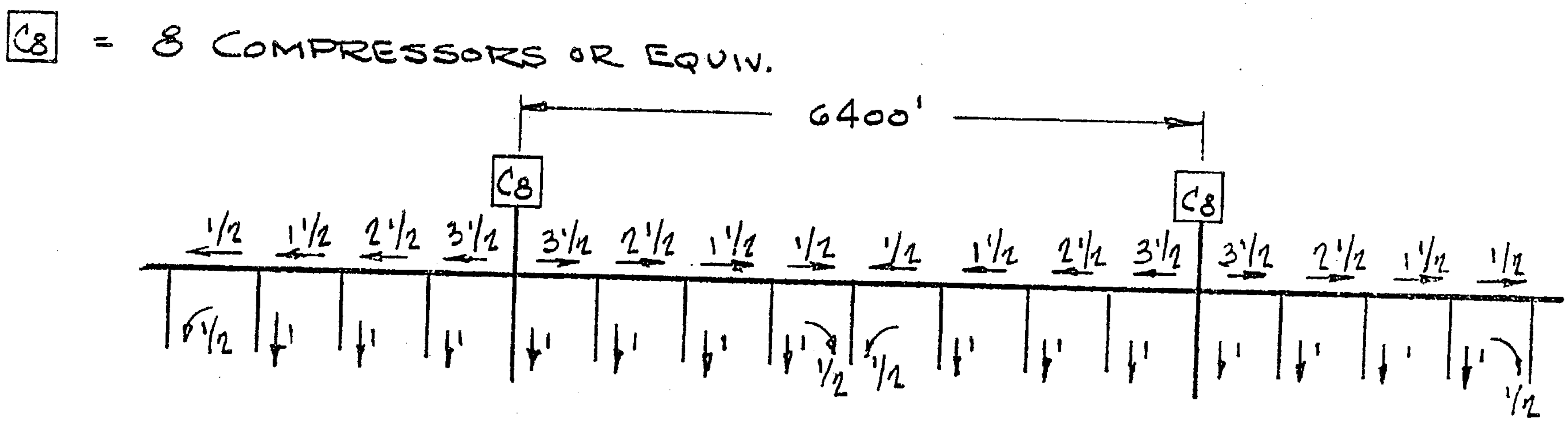

Fig. VI: Case VI - 3 Stations

2. Pressure Drop in Normal Balanced System:

2.1 Pressure Drop in 3 in. IPS, Schedule 5 Pipe Header:

$$\frac{\Delta P}{L} = \frac{f\ g^2}{30\ \rho\ d_L} \times 10^{-9} \text{ psig/ft} \quad (1)$$

Where:

$$g = \text{lb/hr ft}^2$$

$$f = \frac{.046}{Re^{.2}}$$

$$\rho = \text{lb/ft}^3$$

$$d_L = \text{ft}$$

$$Re = \frac{g\ d_L}{\mu}$$

$$\frac{\Delta P}{L} = \frac{.046}{Re^{.2}} \times \frac{g^2}{\rho d_L} \times .033 \times 10^{-9}$$

$$= 1.53\ \frac{g^{1.8}\ \mu^{.2}}{\rho d_L^{\ 1.2}} \text{ psig/ft}$$

At ambient temperature and 20 ata:

ρ = .20 lb/ft^3

μ = .0484 lb/ft hr

$$\frac{\Delta P}{L} = 4.148 \times 10^{-12}\ \frac{g^{1.8}}{d_L^{\ 1.2}} \quad (2)$$

$$\text{Also } g = \frac{\dot{M}}{A} = \frac{\dot{M}}{\frac{\pi}{4} d_L^{\ 2}}$$

Where $\dot{M}$ = flow rate in lb/hr

By substituting this into equation (2), we find:

$$\frac{\Delta P}{L} = 6.4064 \times 10^{-12} \frac{\dot{M}^{1.8}}{d_L^{4.8}} \quad \text{psig/ft} \tag{3}$$

It becomes obvious that the effect of pipe diameter is tremendous. A change from 3 in. to 4 in. IPS, Schedule 5 pipe will reduce the pressure drop by a factor 3.52.

2.2 <u>Pressure Drop in 8 in. IPS, Sch. 5 Pipe Header at Ambient Temperature and 1.05 Ata:</u>

ρ = .01066 lb/ft^3

μ = .0482 lb/ft hr

$$\frac{\Delta P}{L} = 7.832 \times 10^{-11} \frac{g^{1.8}}{d_L^{1.2}} \quad \text{psig/ft} \tag{4}$$

or

$$\frac{\Delta P}{L} = 1.21 \times 10^{-10} \frac{\dot{M}^{1.8}}{d_L^{4.8}} \quad \text{psig/ft} \tag{5}$$

2.3 <u>Pressure Drop in 3 in. IPS, Schedule 5 Header:</u>

Unit Flow Rate $\dot{M}$ = 396.5 lb/hr

Unit Distance L = 800 ft

Header I.D. d_L = .278 ft

$$\frac{\Delta P}{L} = 6.406 \times 10^{-12} \frac{\dot{M}^{1.8}}{d_L^{4.8}}$$

$\Delta P = 2.389 \times 10^{-6}\ \dot{M}^{1.8}$ for 800 ft pipe run

$\dot{M}$	1/2	1	1-1/2	2	2-1/2	3	3-1/2
$P_{D_1} = \Delta P$	.033	.115	.239	.40	.60	.83	1.09

2.4 Pressure Drop in 8 in. IPS, Sch. 5 Header:

Unit Flow Rate $\dot{M}$ = 396.5 lb/hr

Unit Distance L = 800 ft

Header I.D. d_L = .7 ft

$$\frac{\Delta P}{L} = 1.21 \times 10^{-10} \frac{\dot{M}^{1.8}}{d_L^{4.8}}$$

$$\Delta P = 5.363 \times 10^{-7} \dot{M}^{1.8} \quad \text{for 800 ft pipe run}$$

$\dot{M}$	1/2	1	1-1/2	2	2-1/2	3	3-1/2
$P_{S_1} = \Delta P$	.0073	.0255	.0529	.0888	.133	.184	.243

3. Pressure Drop in Unbalanced System Due to One Compressor Breakdown:

3.1 To determine the flexibility of the Cases I through VI, it was assumed that one compressor would suffer downtime. The loss in flow from the one compressor would have to be supplied by the other compressors remaining onstream. The capacity of all compressors must be increased to handle this contingency. In general, if "n" compressors are used, the capacity of each must be increased by a factor of $\frac{n}{n - 1}$ over the normal rating to provide sufficient capacity of the remaining compressors to carry the load if one compressor fails.

Example: If 24 compressors are used, each delivers nominally 396.5 lb/hr for a total flow of 9,516 lb/hr. If one compressor fails, the 4.2% reduction in capacity must be distributed among the remaining 23 units. Therefore, each of the 24 compressors should originally be sized for: $\frac{n}{n - 1}$ (396.5) lb/hr or 413.7 lb/hr.

396.5 lb/hr x 24 = 413.7 lb/hr x 23 = 9,516 lb/hr

When one compressor fails, higher than normal pressure drops will occur in the system due to the redistribution of the flow, the highest value being in the headers between the faulty compressor bank and the next good one. These pressure drops were evaluated for the hypothetical conditions of one compressor failure for each of the cases.

Only the change in pressure drop within the suction and discharge headers were evaluated. It was assumed that flow to and from the cold box and magnets at each station would remain constant and this portion of the system pressure drop would not be affected.

Table I shows a tabulation of normal pressure drops, pressure drops due to one compressor failure, and the changes in pressure drops (ΔP) for both the suction and discharge headers for each case.

3.2 In terms of energy doubler refrigeration, the most important pressure is that of the 8 in. IPS collection header. Temperature of the two-phase fluid in the magnets is determined by the local pressure. If we assume that the base pressure of the compressors is maintained at 1.0 atmosphere, then pressure drop in the header will determine the pressure at the exit of the magnet string. The entrance of the two-phase system at the turnaround box will have the exit pressure plus the pressure drop in the two-phase system.

TABLE I - a

SUCTION

# Stations	# Compr.	Compr. /Sta.	Compr. Cap. #/Hr	Normal Suc. Header Pres. Drop P_{S_1} (Psig)	(1) Compr. Failure Suc. Header Pres. Drop P_{S_2} (Psig)	(1) Compr. Failure Suc. Header Pres. Drop ΔP_S (Psig)
24	24	1	414	-0-	.0073	.0073
12	24	2	414	.0073	.0255	.0182
12	12	1	866	.0073	.0602	.0529
8	24	3	414	.0255	.0559	.0304
8	16	2	635	.0255	.0796	.0541
8	8	1	1360	.0255	.1932	.1677
6	24	4	414	.0602	.1143	.0541
6	18	3	560	.0602	.1262	.0660
6	12	2	866	.0602	.1748	.1146
6	6	1	1904	.0602	.4370	.3768
4	24	6	414	.1932	.2752	.0820
4	20	5	501	.1932	.2983	.1051
4	16	4	635	.1932	.3229	.1297
4	12	3	866	.1932	.3822	.1890
4	8	2	1360	.1932	.5300	.3368
4	4	1	3172	.1932	1.3662	1.1730
3	24	8	414	.4368	.5524	.1156
3	21	7	476	.4368	.5704	.1336
3	18	6	560	.4368	.6073	.1705
3	15	5	680	.4368	.6341	.1973
3	12	4	866	.4368	.6946	.2578
3	9	3	1190	.4368	.8182	.3814
3	6	2	1904	.4368	1.1244	.6876
3	3	1	4760	.4368	3.0640	2.6272

TABLE I - b

DISCHARGE

# Stations	# Compr.	Compr. /Sta.	Compr. Cap. #/Hr	Normal Dis. Header Pres. Drop P_{D1} (Psig)	(1) Compr. Failure Dis. Header Pres. Drop P_{D2} (Psig)	(1) Compr. Failure Dis. Header Pres. Drop ΔP_D (Psig)
24	24	1	414	-0-	.033	.033
12	24	2	414	.033	.115	.082
12	12	1	866	.033	.272	.239
8	24	3	414	.115	.2506	.136
8	16	2	635	.115	.3575	.243
8	8	1	1360	.115	.8720	.757
6	24	4	414	.272	.515	.243
6	18	3	560	.272	.566	.294
6	12	2	866	.272	.785	.513
6	6	1	1904	.272	1.962	1.690
4	24	6	414	.872	1.236	.364
4	20	5	501	.872	1.345	.473
4	16	4	635	.872	1.450	.578
4	12	3	866	.872	1.716	.844
4	8	2	1360	.872	2.380	1.508
4	4	1	3172	.872	6.142	5.270
3	24	8	414	1.962	2.480	.518
3	21	7	476	1.962	2.561	.599
3	18	6	560	1.962	2.735	.773
3	15	5	680	1.962	2.847	.885
3	12	4	866	1.962	3.119	1.157
3	9	3	1190	1.962	3.682	1.720
3	6	2	1904	1.962	5.049	3.087
3	3	1	4760	1.962	13.769	11.807